INNOVATIONS OF BARN CONSTRUCTIONS FOR BETTER PARAMETERS OF THE BREEDING ENVIRONMENT

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Abstract
The aim of this study was to determine the concentrations of harmful gases and microclimate parameters of the indoor air in two different building and construction types of dairy housing in the summer season with an emphasis on evaluating the effect of structural innovation, air chemistry and animal thermal load indices, as well as parameters of the quality of the employees' environment. The results consisting of measurements of microclimatic parameters, measurements of pollutant concentrations and calculation of the heat load indexes THI and ETIC, showed a partial reflection of various building and construction solutions for the quality of the breeding environment. During hot summer days, no significant differences in heat load indices were detected between the low-volume object (where VA=34.3 m^3 per animal) with 5 basket sliding fans (total output 82500$m^3.h^{-1}$) compared to the index values in the large-volume object with natural ventilation (where VB =82.5 m^3 per animal). The concentrations of CO_2, NH_3, CH_4 and H_2S were significantly lower in the large-volume object ($P<0.01$), which, including the design conditions, predicts more effective conditions for ensuring the required environmental hygiene.

Key words*: cattle housing, gas concentrations, temperature-humidity index, equivalent temperature index.*

INTRODUCTION
Agriculture and animal husbandry are important sources of greenhouse gas (GHG) emission and contribute to climate change (*Li et al., 2021*). Emissions of ammonia (NH_3) and greenhouse gases, e.g. methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O), from livestock production systems are of great concern to livestock producers, environmentalists, and governments due to their negative impact on surrounding environment and global climate (*Kavanagh, 2019*). Their high concentration in production buildings has a negative effect on both livestock and livestock breeders. Poor ventilation can increase the relative humidity and the concentration of harmful gases such as carbon dioxide and ammonia. The concentration of carbon dioxide depends to a large extent on the type of building, the ventilation system and the density of the animals. Many factors influence the concentrations of harmful gases, in especially high temperature, emitting area and emission source, etc. Due to climate change, even in temperate climates, the issue of high air temperatures and increased heat load is increasingly becoming more common and affects high producing dairy cows the most (*Herbut, 2021*). One option to reduce heat load in dairy cows is by using flow cooling through natural and forced ventilation. Natural ventilation is dependent on weather and structural design and is often not adequate in summer. Then it is required to provide cooling by forced ventilation or by a combination of several methods - evaporative cooling, shading, spraying of animals, etc. (*Fournel, 2017; Doležal, 2010*). To assess the quality of the environment, in scientific practice, combined methods are used - part of practical measurements and part of theoretical calculations, or the detection of production or health indicators. The worst combination is when extremes in both high concentration of pollutants and high heat load of animals occur. The article is devoted to the comparison of the state of air chemistry and the level of heat load in two structurally different types of housing buildings.

MATERIALS AND METHODS
The study was performed during the summer season in two types of dairy cattle barns with different process and technical systems, in the old (A) and new building (B) in the same farm. The barns differed in herd size, housing system, and manure management. The older three-row building A (Fig. 1) was 11.5 m wide and 70 m long, with a side (longitudinal) wall height of 4.3 m and a total height of 9.7 m

at the ridge. The building had 3 rows of diagonally arranged cubicles for free housing of 158 dairy cows. One row of cubicles was oriented directly to the wall, and it was separated from the double-row cubicles by an internal movement corridor 2.45 m wide. An outdoor feeding area with a length of 70 m and a width of 3.25 m was added to the building. The ceiling parts were removed due to an increase in the volume of the building from the original 2,329.6 m^3 to 5,154.1 m^3. The ridge of the roof was opened to at a width of 350 mm and parts of the roof covering were illuminated by five vertical strips 1 m wide. Milking took place twice a day, ad libidum feeding with supplementary feeding twice a day. There were 34.3 m^3 per animal in the building, area of 4.85 m^2 per animal in the interior and 6.37 m^2 per animal including the outdoor covered feeding area. Five basket fans were installed in the longitudinal axis above the double-row of cubicles, each with a capacity of 16,500 m^3h^{-1} (total 82,500 m^3h^{-1}). Cleaning of cubicles and corridors was carried out twice a day, coordinated to milking time. Fresh litter up to 100 mm thick was spread daily during morning milking.

The new eight-row building B (Fig. 2) for 444 dairy cows (Czech spotted cattle) had two internal feeding corridors, the length of the building was 85.4 m with the height of the 3-sector counter roof in the ridge of 18.2 m. The height of the wall was h_s=8 m on the south side, h_n=6.5 m on the north side. The front walls were made of Agropanels with a thickness of 40 mm, 8 gates for the entry of the mechanisms were made up of remote-controlled green plastic blinds. The roller shutter system was also used on the side walls, where a fully openable roller shutter 85 m long and 4.8 m high was made above the 2.1 m high fixed wall. The roof area was composed of three roof boards - the southern area made of Agropanels 1,500 m^2, the middle area made of double-cavity polycarbonate corrugated roofing 1,865 m^2 at a slope of 15° and the northern Agropanel-roof area of 1,440 m^2 at a slope of 24°. Two large vertical slits were made along the entire roof, which ensure the removal of air through natural ventilation. The upper continuous intermediate opening in the ridge was 3.3 m high, the second roof opening was 1.5 m high. The deepened cubicles were 2,700 mm long in a single-row and double-row arrangement (head-to-head) with a depth of 0.3 m in the filling area. This part of the bed was made of moistened and compacted straw and limestone, which was leveled with the height of the litter threshold. A fresh layer of chopped wheat straw (approximately 100 mm thick) was applied daily to this permanent foundation. This layer was cleaned twice a day with subsequent removal of all excrement.

The concentrations of CH_4, NH_3, N_2O, and CO_2 were measured using a photo-acoustic multi-gas analyser 1309 (Inova, Denmark). The measurement of gas concentrations inside the breeding environments was located on the sampling points according to Fig.1 and Fig. 2 at a height of 1.8 m above the floor. The outdoor location was chosen along either side of the barn at the height of about 2 m above the ground. The average air temperature and relative humidity were measured every 5 min using datalogger Comet. Three data loggers were placed close to the gas sampling locations inside the barn, and two data loggers were placed outside the barn. The two types of indexes were used to evaluate the heat load of animals. The temperature humidity index (THI) was calculated according to *Kelly & Bond, (1971)*. There are four load levels: mild heat stress 72 < THI < 79, moderate stress 80 < THI < 89 and severe heat stress THI > 89 (*Hoffmann et al., 2020*). The Equivalent Temperature Index for Dairy Cattle (ETIC - calculated according to *Wang et al., 2018*) takes into account - in addition to temperature and relative air humidity - air velocity and solar radiation (*Hempel et al., 2019*). There are also four load levels: mild category 18 ≤ ETIC < 20, moderate category 20 ≤ ETIC < 25, severe category 25 ≤ ETIC < 31, emergency category 31 ≤ ETIC (*Hempel et al., 2019*). The quality of the workers' working environment was evaluated according to Act No. 355/2007 and Decree No. 99/2016. The aim of this study was to determine the concentrations of harmful gases and microclimatic properties of indoor air in two different building and construction types of dairy housing in the summer season with an emphasis on the evaluation of the effect of structural innovation on air chemistry and animal heat load indexes, as well as parameters of the quality of the employees' environment.

Statistical analysis

Data on climatic parameters, gas concentrations in two barns with different housing systems were processed statistically. Since all variables had a normal distribution, single factor ANOVA was performed. The significance of differences between the mean values of gas concentrations in barns was determined by Tukey's test. All calculations were made using Statistica 10 for Windows (StatSoft, CZ).

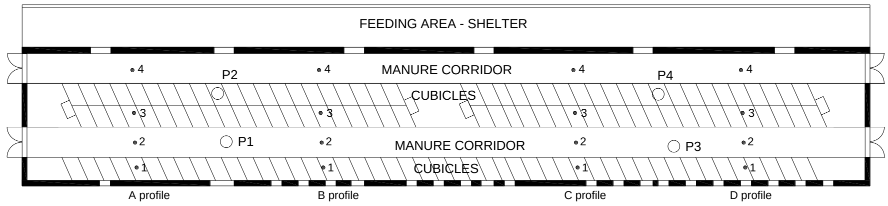


Fig. 1 Floor plan of object A with measuring points P1 – P4 of gases and points 1 - 4 of measuring microclimate parameters

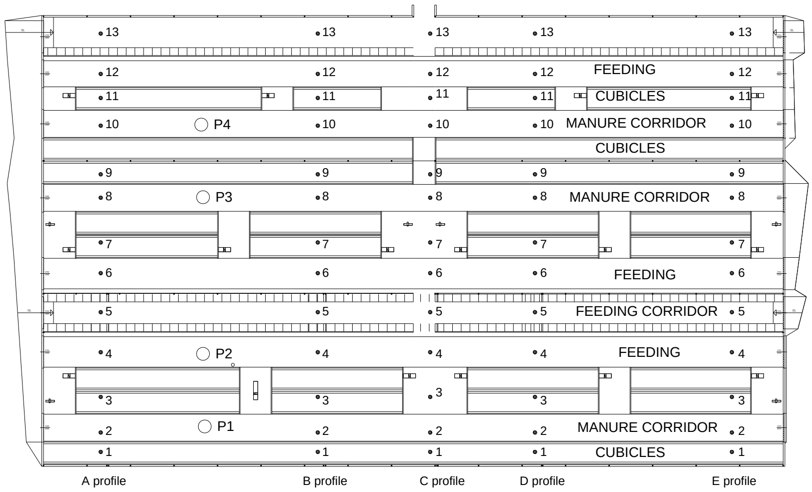


Fig. 2 Floor plan of object B with measuring points P1 – P4 of gases and points 1 - 13 of measuring microclimate parameters

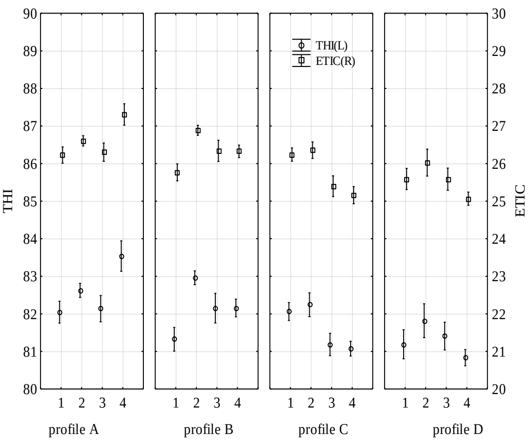
RESULTS AND DISCUSSION

The results of the on-farm measurements and climate index calculations are shown in Figures 3 and 4. The optimum temperature in dairy cow housing is 8-16°C (*Gálik et al., 2015*). As aspected - in neither building was the optimal temperature ensured. In the location of Central Europe, this is almost impossible during the day in summer. Moreover, the methodology of the experiment was aimed at monitoring situations during days with extremely high outdoor air temperatures, so that air chemistry and heat load were assessed for critical cases. The climatic data was recorded during the period with outdoor air temperature 30°C<T_{ex}t<32°C, relative humidity 47%<RH_{ext}<53% and airflow velocity 0.2 $m.s^{-1}$<v_{ext}<1.2 $m.s^{-1}$. During the assessment of indoor climate parameters, no significant differences were found between objects A and B (P>0.05), however, in accordance with the methodology - fans were not installed in building B. The intention of the breeder was to provide the new building with a large-cubicle space with low-energy, quiet and low-emission operation. Mean concentrations of greenhouse gases and ammonia differed significantly (P<0.01) between facilities. Building B (new) was characterized by lower (P<0.01) mean concentrations of GHGs and ammonia compared to Building A (Table 1). The detected amounts of all gases were lower than the recommended environmental limits for workers and animals during the experiment. The microclimate in the stables has both direct and indirect effects on animal health, as it significantly influences the emissions and concentrations of ambient gaseous gases such as greenhouse gases, ammonia and VOCs. The release of NH_3 and CO_2 from manure is determined by the temperature and moisture content of the straw, among other factors (*Witkowska & Sowinska, 2017*). The observed differences in GHG concentrations can be attributed to the different technological systems in the analysed barns. According to *Dimov et al. (2019)*, temperature and relative humidity are related to CO_2 levels. In the study (*Dimov et al., 2019*), the lowest CO_2 concentrations and the smallest variations in CO_2 levels were recorded in barns with automated and robotic cleaning systems. In our experiment, the average CO_2 concentration in the new barn (B) was 9.8% lower than in barn A. The most significant improvement in chemistry was observed for NH_3, which was 34.2% lower in the new facility, and CH_4

concentrations were 41.5% lower than in the old facility. Microclimatic parameters are an important physical factor of the working environment that affects working conditions in workplaces. For this reason, in our legislation (§ 37 of Act No. 355/2007) lays down the basic obligations of employers to protect the health of employees against the burden of heat and cold at work, and Decree No. 99/2016 of the Ministry of Health of the Slovak Republic lays down details related to the protection of the health of employees against the burden of heat and cold at work. For working class "1b", the optimum temperature is T_{op}=22-25°C (T_{min}=19°C, T_{max}=27°C), permissible relative humidity RH=30-70% and permissible air velocity v≤0.3 m.s^{-1}. However, the daily tasks of the staff working to provide the necessities of life and hygiene in the housing facilities are not continuously tied to their permanent performance only in those facilities during working hours. Especially in a new facility, the working time in the barn is reduced to the time necessary for the operation of machinery, possible repairs and maintenance. The longest stays are for the treatment of animals, part of which is usually carried out by external staff - the veterinary service. The construction of the building with a new structural design and innovative housing technology has increased the comfort of the housed animals and the air quality in terms of ammonia production, greenhouse gases as well as microclimatic parameters.

Tab. 1 The minimum, maximum values and average values of all measurements of gases, temperature and relative humidity

	old three-row building A				new eight-row building B				Limit values mg.m^{-3}
gas con-centr. mg.m^{-3}	average	min	max	st. dev.	average	min	max	st. dev.	
CO_2	1422.9	852.1	2619.7	290.6	1295.3	912.5	2045.8	170.7	4582
NH_3	2.5	1.1	5.1	0.6	1.8	0.7	4.1	0.4	17.6
CH_4	22.9	6.8	60.4	9.1	16.2	7.9	76.8	5.0	666
N_2O	0.9	0.6	3.7	0.1	0.8	0.5	1.3	0.1	180
H_2S	1.5	0.7	3.3	0.2	1.3	0.4	2.7	0.3	14



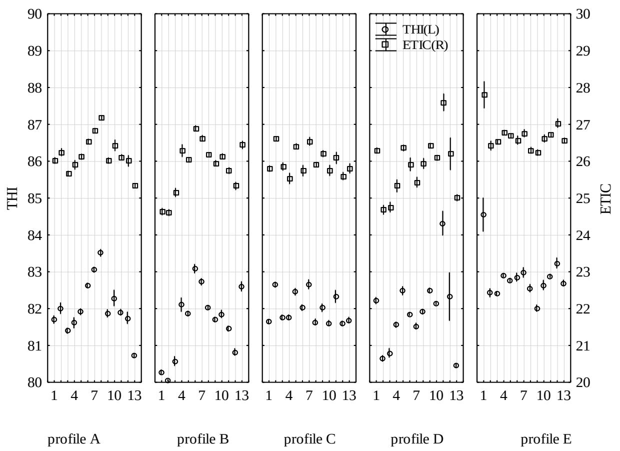


Fig. 3 left: results of the evaluation of the THI and ETIC heat load indexes in building A. The average values found by measurements and calculation from the 16 measurement locations in the old building were: THIA,AVG=81.93±0.87 and ETICA,AVG=26.09±0.71; right: results of the evaluation of the THI and ETIC heat load indexes in building B. The average values found by measurements and calculation from 65 measurement locations in the old building were: THIB,AVG=82.09±0.89 and ETICB,AVG=26.12±0.71.

The productivity of labour has also increased, the cubic volume of the environment has increased from the original V_A=34.3m^3 to the new V_B=82.5 m^3 per cow. These results are in accordance with the statement of *Pogran et al. (2011)* that the construction-technological design of buildings for livestock production has a significant impact on the formation of the indoor environment, which is formed by the air content of the housing space, the temperature and humidity of the air, its movement and stratification, the amount of solid, gaseous (CO_2, NH_3, H_2S) and bacterial parts. Long heat waves have a strong influence on the impairment of welfare and reduced performance of dairy cows (*Herbut et al., 2021*). Management strategies for cows against heat stress can be summarized into the following components: physical environmental modification, genetic development of heat-tolerant breeds, and improved nutritional management practices (*Johnson, 2018*). Construction parameters are also essential in the context of ventilation (*Drewry et al., 2018*). Air quality variability also influences the quality of the animal environment and the working environment of caregivers, as well as the quality of bedding, which secondarily also influences animal welfare (*Némethová et al., 2020*). The design of ventilation openings in buildings with natural ventilation is also an important element subject to beneficial innovative changes *Li et al. (2021)*. In accordance with his testing, the design of the side walls of barn B of our experimental farm stands out, where the wall openings occupied the area, protected by a controllable roller shutter system, $A_{B,w}$=882 m^2. The vertical openings between the roof slabs with the area of the upper opening $A_{B,1}$=280 m^2 and the lower vertical opening $A_{B,2}$=127 m^2 effectively helped the flow regime. In total, there were 2.7 m^2 of structural openings per animal in barn B.

CONCLUSIONS

On the dairy farm located 287 m above sea level, during hot summer days with an indoor air temperature T_{avg} > 32°C in a three-row barn with a lower cubic capacity (V_{Aa} = 34.3 m^3 per animal) with motoric ventilation and a total capacity of 82,500 $m^3.h^{-1}$ (Q = 522 m^3 per animal) – there were THI_{avg} = 81.93±0.87 and $ETIC_{avg}$ = 26.09±0.71. According to our measurements, the installation of more powerful fans would be necessary, and especially the installation of fans even in the single row of cubicles along the wall, which is technically difficult. If an increase in air velocity by 1 $m.s^{-1}$ is achieved, theoretically the air exchange in the building could be increased from 28.4 h^{-1} to 68.9 h^{-1}, where the recommended value of ACH>80 h^{-1}. This solution would help in moisture reduction, but according to THI calculations, even with a 10% drop in relative humidity, this would not be able to adjust the degree of heat load to the required level (THI<72). The ETIC index responds more flexibly not only to relative humidity but also to an increase in flow velocity, but to achieve the required value of ETIC = 20, it would be necessary to ensure an average airflow velocity of v>7.1 $m.s^{-1}$, which is irrational. Also the additional cooling of the animals by evaporative cooling has limitations in this building due to the necessary ventilation of the additional humidity and it would be more rational to use it in an outdoor feeding area, where - it does not affect the interior effect, however. Moreover, even with the use of motorized ventilation, the NH_3 and CH_4 levels were more than 34.2% and 41.5% higher, respectively, than in the new eight-row large cubicle building without the use of fans. The investment of the new building was increased by the higher cubature (V_{Ba}=82,5 m^3 per animal), mainly by the size of the openings. These are advantageously used during the whole year with a natural ventilation system that works cost-free, without additional energy and noise. The large openings in the wall are covered with plastic roller shutters with adjustable height up to 4.8 m, which is not a costly element at the prices of building components. The openings in the roof are uncovered, thus at no cost. In a large cubature building, in addition to lower concentrations of harmful gases, we found spatial and installation advantages of using cyclonic fans, which, with unit capacities of 55,000 $m^3.h^{-1}$ to 85,000 $m^3.h^{-1}$ and their regulatability, would increase heat removal in the summer and, in the case of increased humidity, from the elements of evaporative cooling. To make the effect of the ventilation technique more effective, it would be advisable to prepare simulations of the distribution of fans using baffle shutters and subsequent more detailed research to assess the balance of the benefits of using forced ventilation in such a building design.

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